A 1.5 h course to be held at the JRC Ispra at the 5th International Summer School 2013:
Operational Issues in Radioactive Waste Management and Nuclear Decommissioning

Nucleonica "Lab"

Case Study: Characterisation of an irradiated fuel sample (UOX) from a PWR

Dr. Joseph Magill,
Nucleonica GmbH,
Karlsruhe

Case Study: Characterisation of an Irradiated fuel sample (UOX) from a PWR

A: Calculate the activities of actinide and fission products in the sample (webKORIGEN)

B: Create a nuclide mixture of the 10 nuclides with highest activities (Nuclide Mixtures)

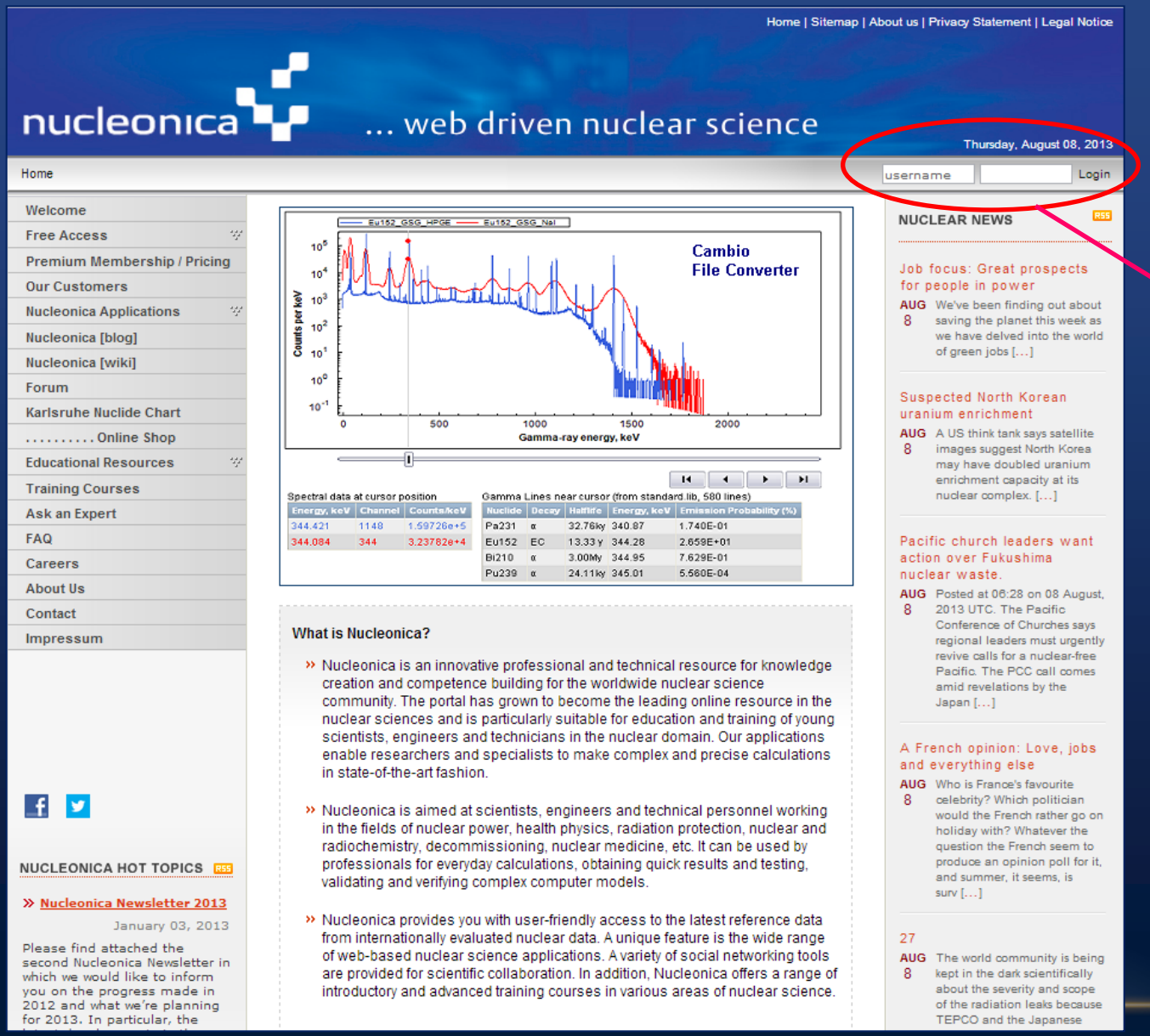
C: Estimate the gamma dose rate from this material – both unshielded and shielded (Dosimetry & Shielding)

D: Generate the gamma spectrum for a HPGe detector (Gamma Spectrum Generator) and identify the main lines.

E: Generate a transport report to determine which type of packaging is required to transport this sample (e-Ship)

F: Use the Decay Engine++ to see how the activity of the sample decreases over 5000 y.

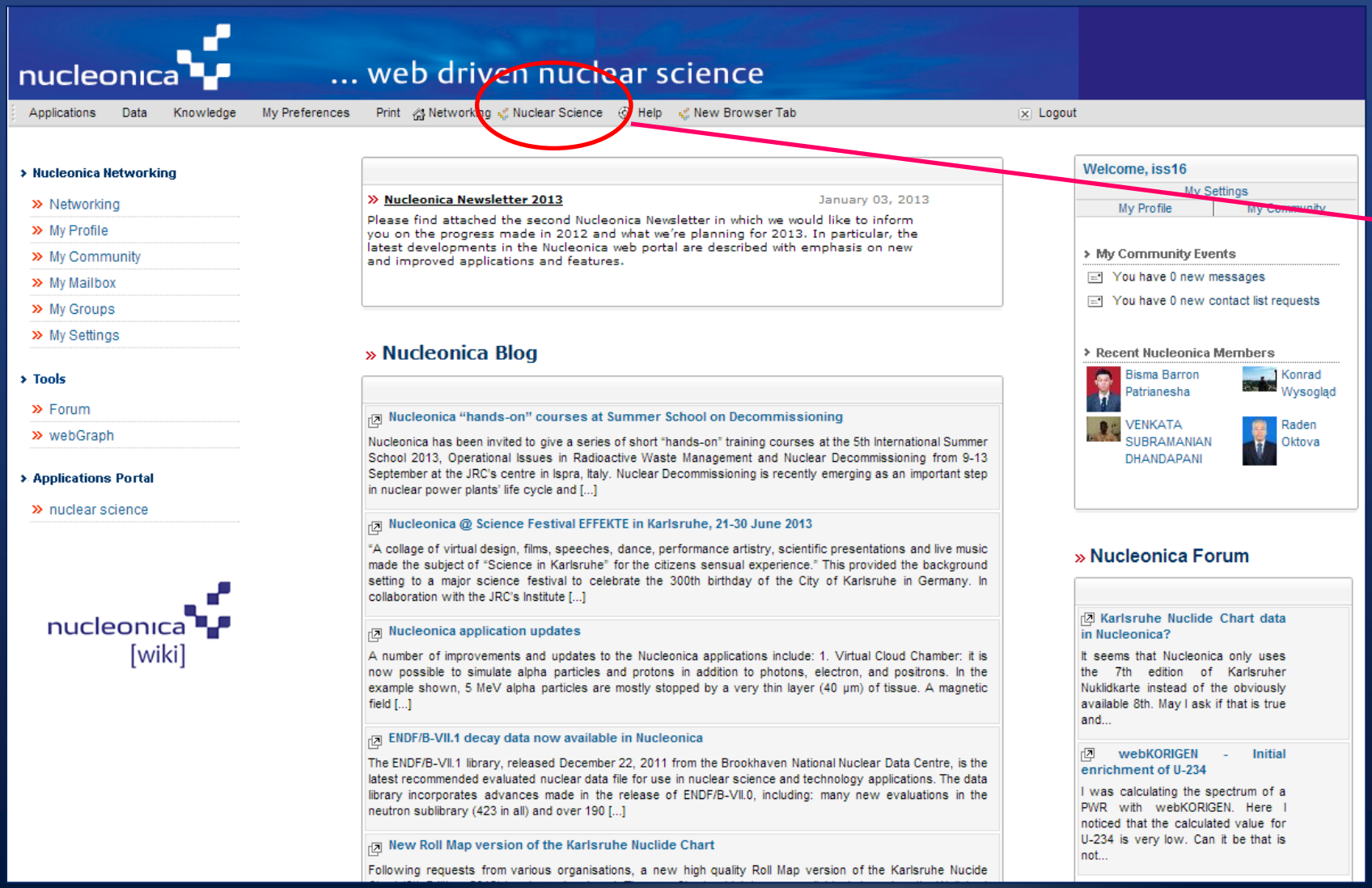
1. Open browser and go to www.nucleonica.com



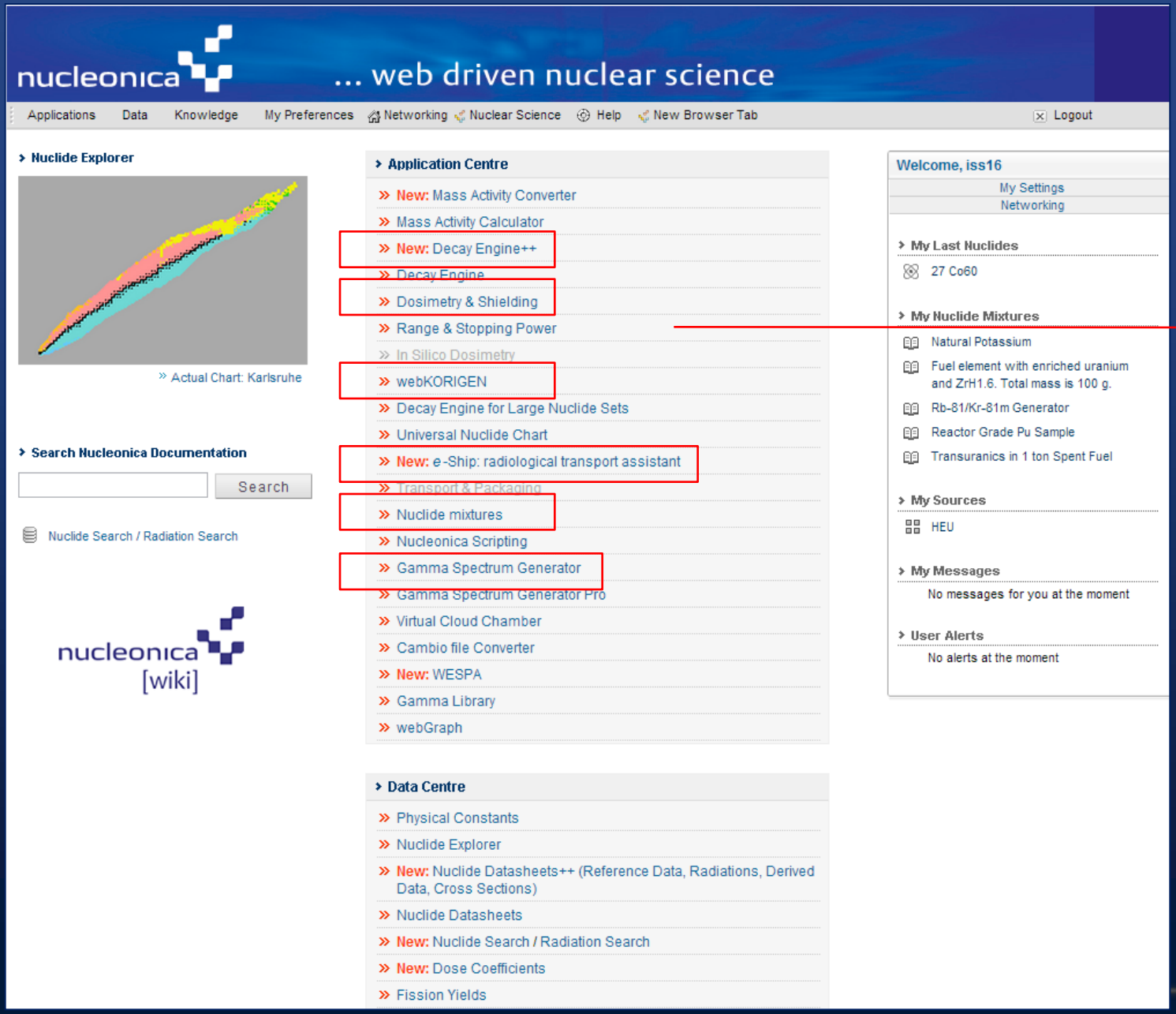
2. Enter your username and password (iss*) e.g. iss16

nucleonica

3. You will then enter the Networking page…



4. Now go to the Nuclear Science page



5. Here are the applications we are going to use

nucleonica

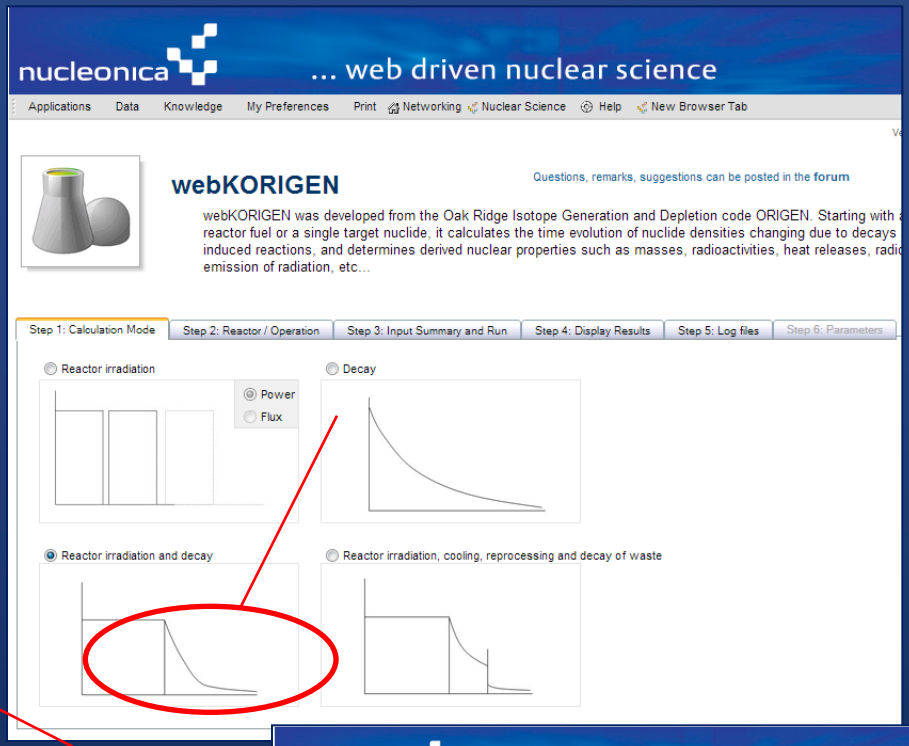
A: Calculate the activities of actinide and fission products in the sample. (webKORIGEN)

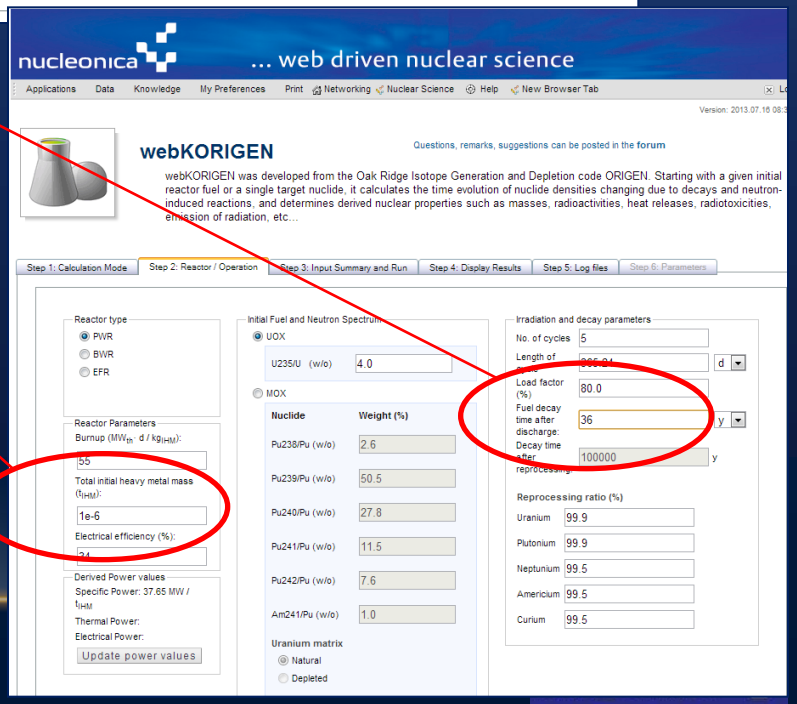
1. Start the webKORIGEN application

2. Select mode 3: Reactor irradiation and decay

3. Use a fuel mass of 1g. Take a cooling time of 36 years. Otherwise default values

4. Run the application (go to tab 3)



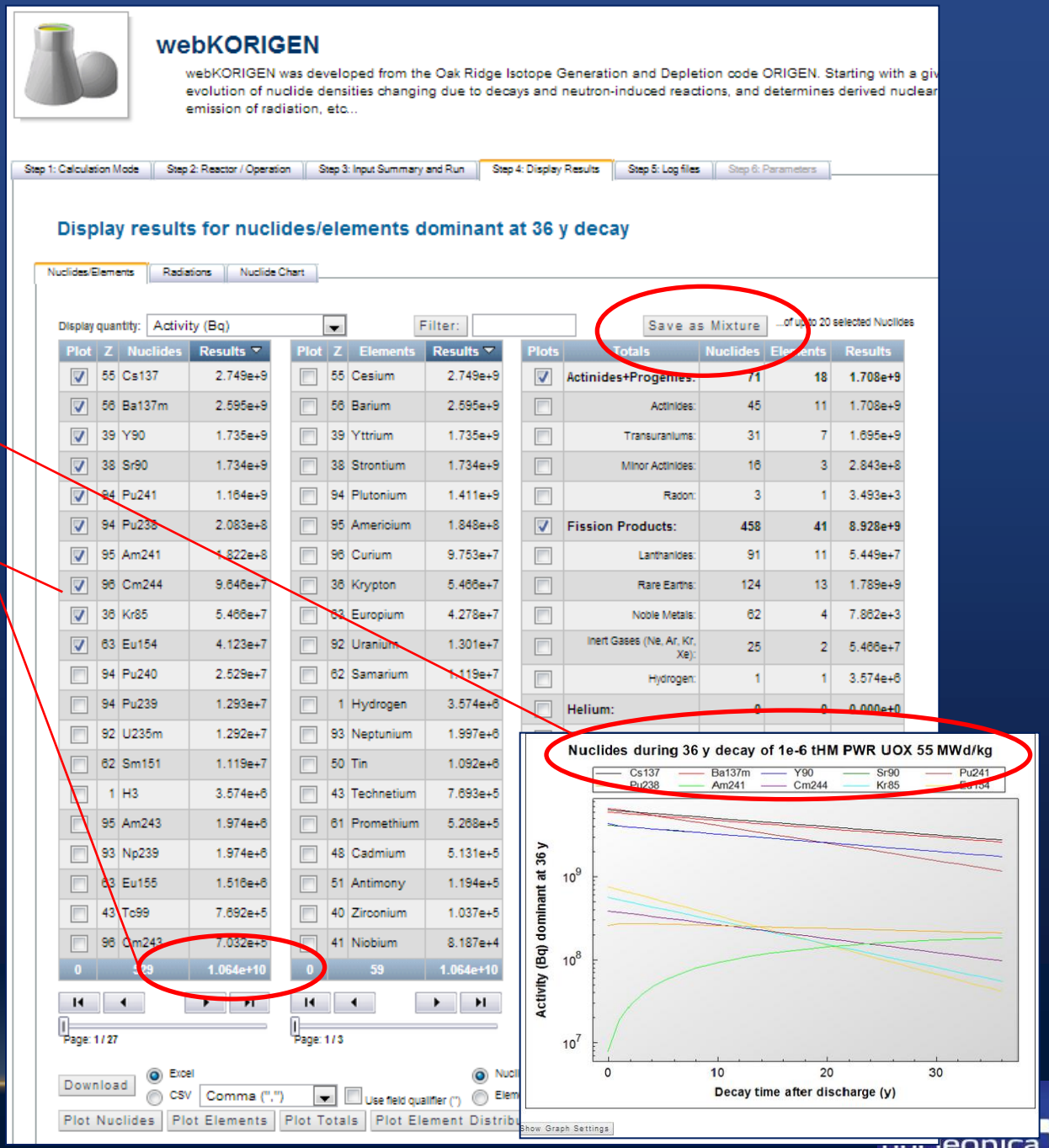


4. Run the application.

5. Select activities of the main nuclides (Total activity is 10.6 GBq)

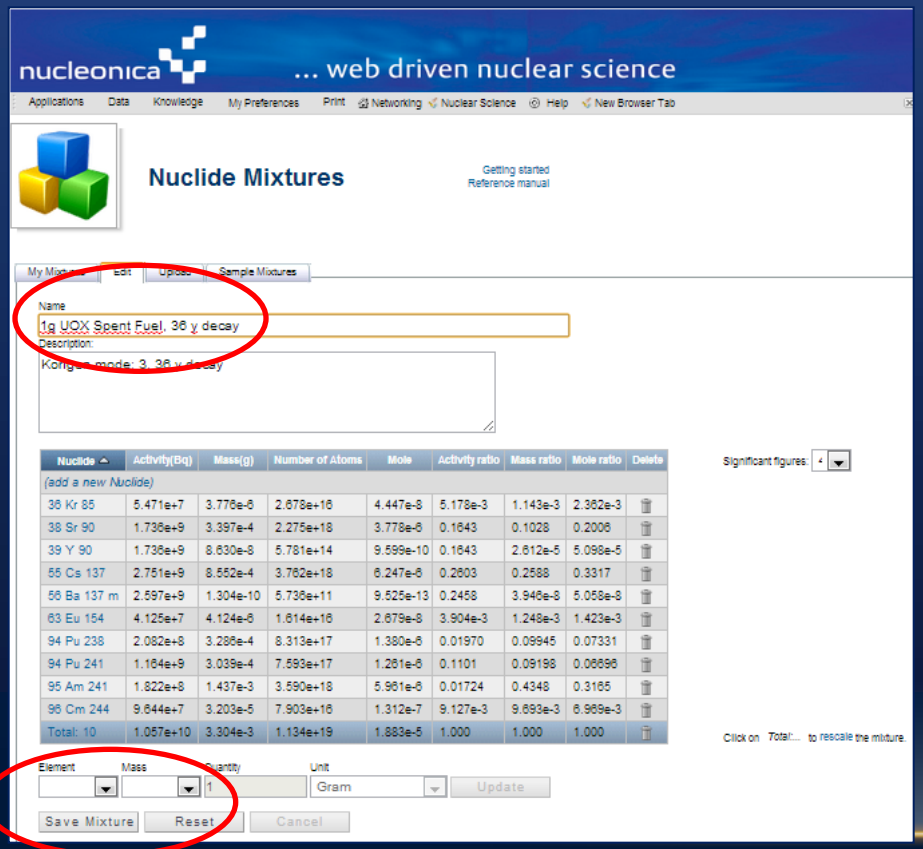
6. Plot the activities over the 36 y cooling period

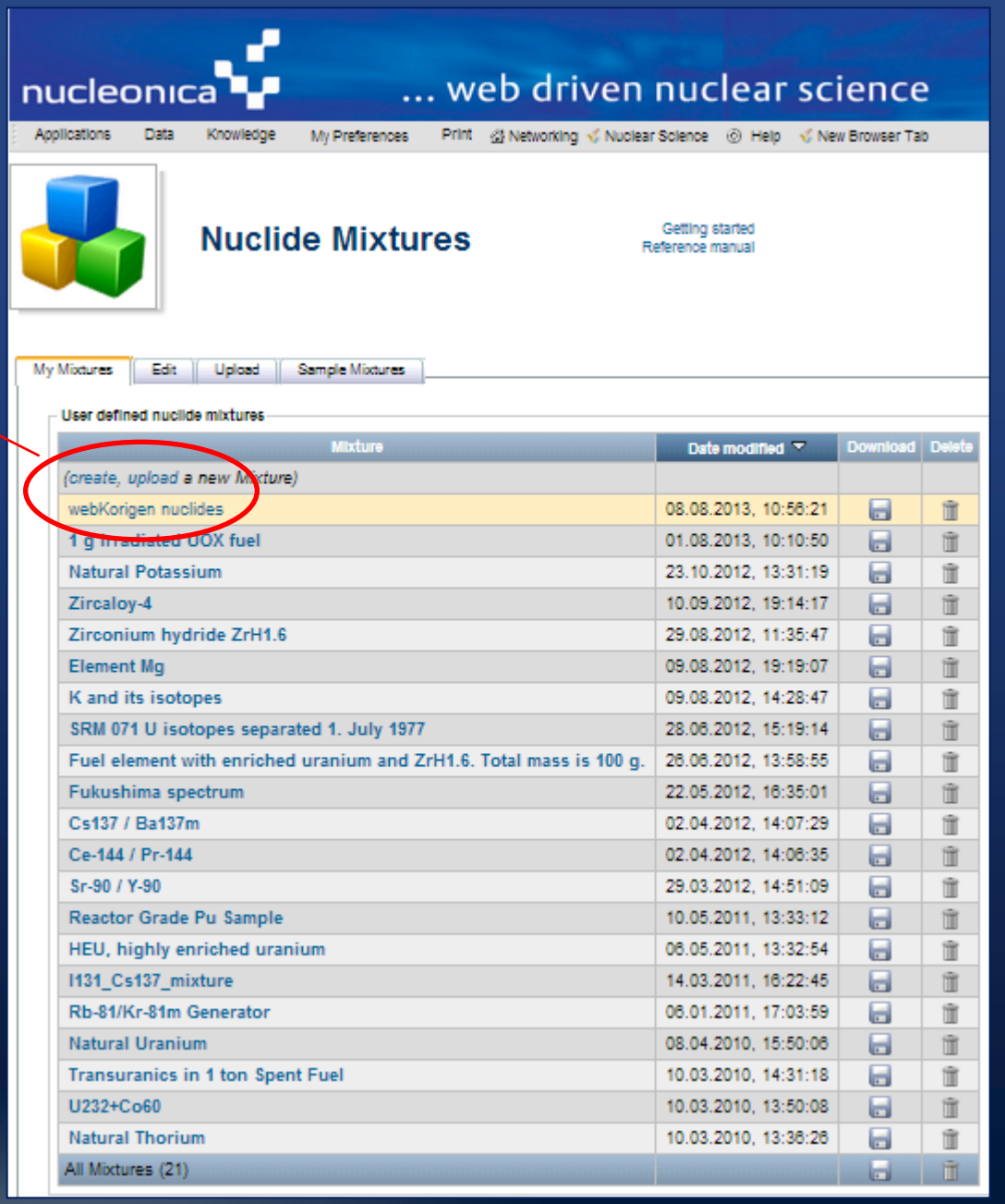
7. Check the top 10 activities and create a nuclide mixture based on these nuclides. Rename the nuclide mixture.



B: Create a nuclide mixture of the 10 nuclides with highest activities (Nuclide Mixtures)

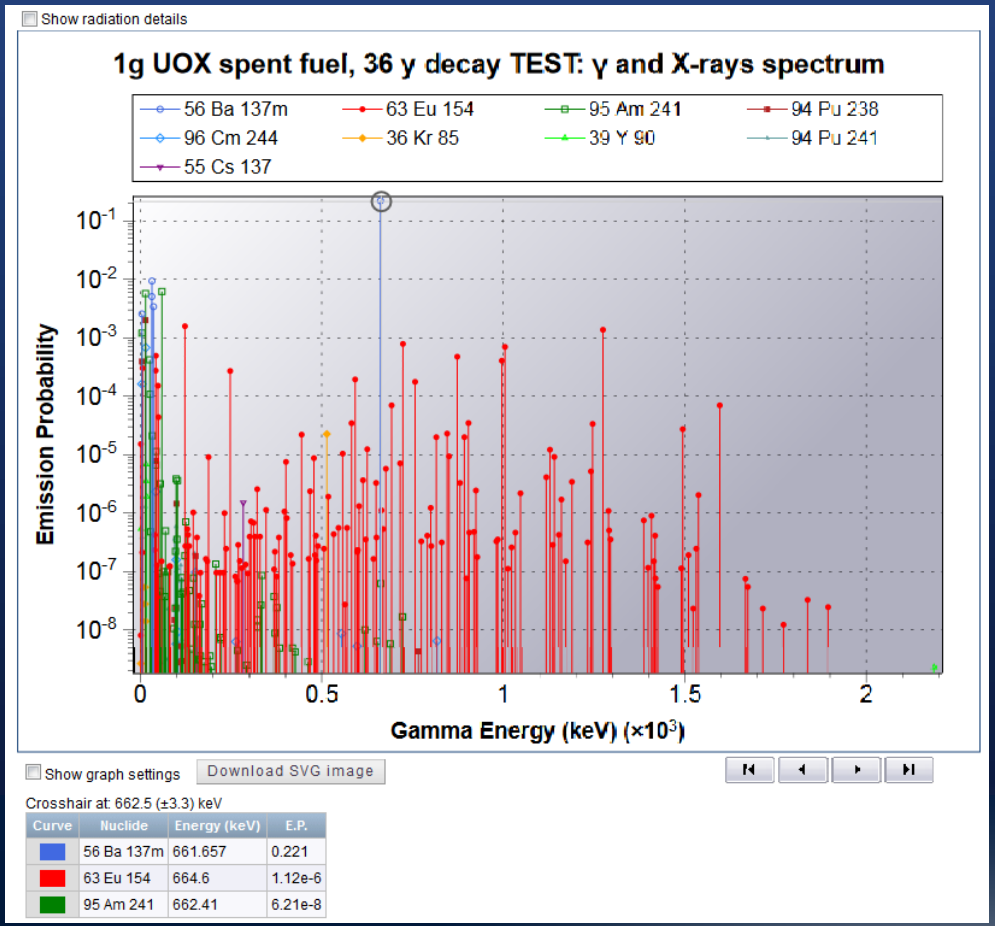
1. Rename the mixture to…
   1g UOX spent fuel & save

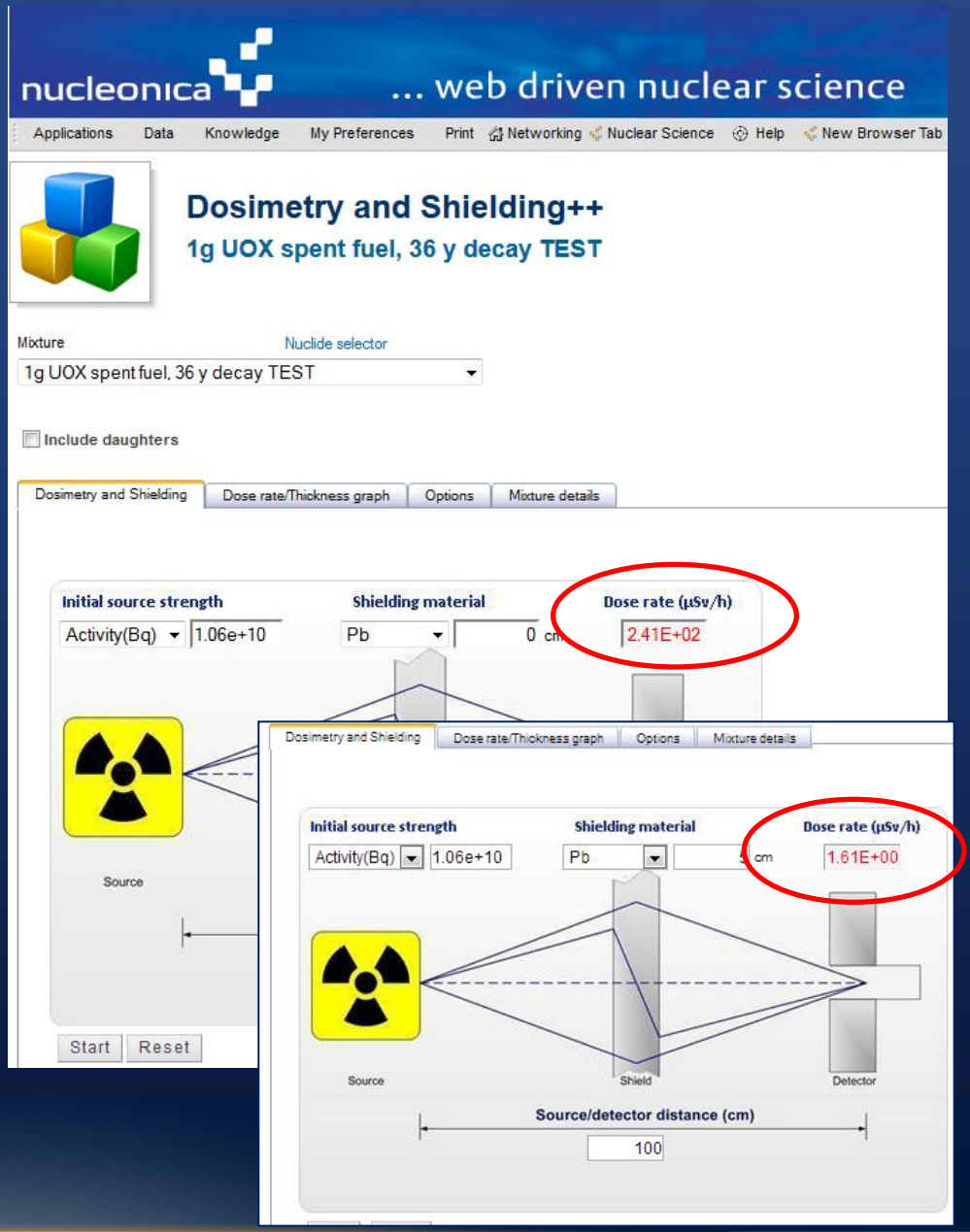




nucleonica

C: Estimate the gamma dose rate from this material – both unshielded and shielded (Dosimetry & Shielding)





Half-Value Shield Thickness(cm)	9.50E-01
Tenth-Value Shield Thickness(cm)	2.48E+00
Equivalent Dose Rate Constant Γ(mSv·m²/GBq/h)	2.28E-02
Tissue Gamma Dose Rate (µSv/h)	**1.61E+00**
Exposure Rate (µGy/h)	1.47E+00
Effective Build-up factor	2.85E+00
Effective Number of Mean Free Paths (µ·d)	6.06E+00
Operational Quantities:	
Specific ambient dose rate equivalent h_{10} (mSv/h/GBq) @ 1m	3.51E-02
Specific ambient dose rate equivalent $h_{0.07}$ (µSv/h/GBq) @ 1m	< 1.14E+01

Download Excel CSV Separator: Semicolon (";") Use field qualifier (")

Number of lines (γ):	397	ΣE.P.(γ):	1.85E+06
Number of lines (X):	52	ΣE.P.(X):	2.16E+04
Number of lines (γ+X):	449	ΣE.P.(total):	1.88E+06

Download Excel CSV Separator: Semicolon (";") Use field qualifier (")

Nuclide	Half-life	Activity (Bq)	Mass (g)	Tissue γ Dose Rate (µSv/h)	γ Exposure rate (µGy/h)
36 Kr 85	10.776 y	5.49E+07	3.79E-06	7.98E-06	7.25E-06
38 Sr 90	28.79 y	1.74E+09	3.41E-04	0.00E+00	0.00E+00
39 Y 90	64.00 h	1.74E+09	8.66E-08	1.20E-06	1.12E-06
55 Cs 137	30.1671 y	2.76E+09	8.58E-04	7.48E-15	6.45E-15
56 Ba 137m	2.55 m	2.60E+09	1.31E-1	1.18E+00	1.08E+00
63 Eu 154	8.593 y	4.14E+07	4.14E-06	4.32E-01	3.96E-01
94 Pu 238	87.7 y	2.09E+08	3.30E-04	1.60E-07	1.47E-07
10 Nuclides	**Page: 1 / 2**	**1.06e+10**	**3.31e-3**	**1.61e+0**	**1.48e+0**

Download Excel CSV Separator: Semicolon (";") Use field qualifier (")

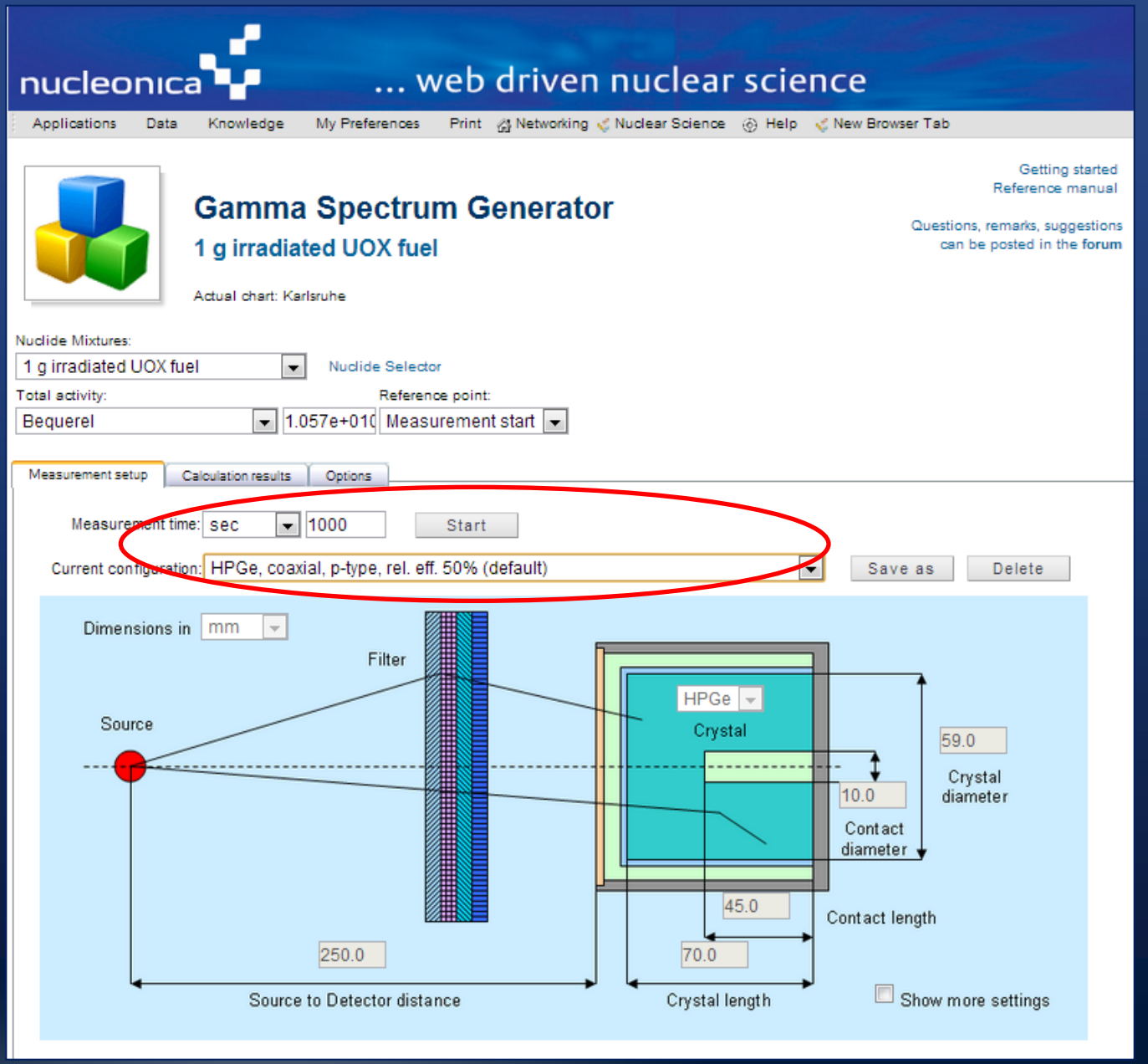
Show radiation details

Nuclide	Gamma Energy (keV)	Emission Probability P (per disintegration)	Mass Attenuation Coefficient (shielding)(cm²/g)	Number of Mean Free Paths (µ·d)	Build-up Factor	Mass Absorption Coefficient (tissue)(cm²/g)	Tissue γ Dose Rate(µSv/h)	γ Exposure Rate(µGy/h)
56 Ba 137m	661.657	2.21E-01	1.11E-01	6.31E+00	2.83E+00	3.23E-02	1.18E+00	1.08E+00
63 Eu 154	1274.69	1.37E-03	5.81E-02	3.29E+00	2.86E+00	2.93E-02	2.63E-01	2.40E-01
63 Eu 154	1004.57	6.98E-04	7.07E-02	4.01E+00	3.00E+00	3.07E-02	5.67E-02	5.15E-02
63 Eu 154	996	4.06E-04	7.13E-02	4.05E+00	3.00E+00	3.07E-02	3.17E-02	2.97E-02
63 Eu 154	1596.5	7.00E-05	5.08E-02	2.88E+00	2.76E+00	2.76E-02	2.31E-02	2.13E-02
63 Eu 154	873.236	4.74E-04	8.13E-02	4.61E+00	2.98E+00	3.14E-02	1.87E-02	1.71E-02
63 Eu 154	723.43	7.86E-04	1.00E-01	5.68E+00	2.90E+00	3.20E-02	8.81E-03	8.11E-03
63 Eu 154	1494.1	2.73E-05	5.23E-02	2.97E+00	2.80E+00	2.81E-02	8.03E-03	7.60E-03
63 Eu 154	1246.2	3.36E-05	5.90E-02	3.35E+00	2.87E+00	2.94E-02	6.07E-03	5.74E-03

C: Estimate the gamma dose rate from this material –
both unshielded and shielded (Dosimetry & Shielding)
details

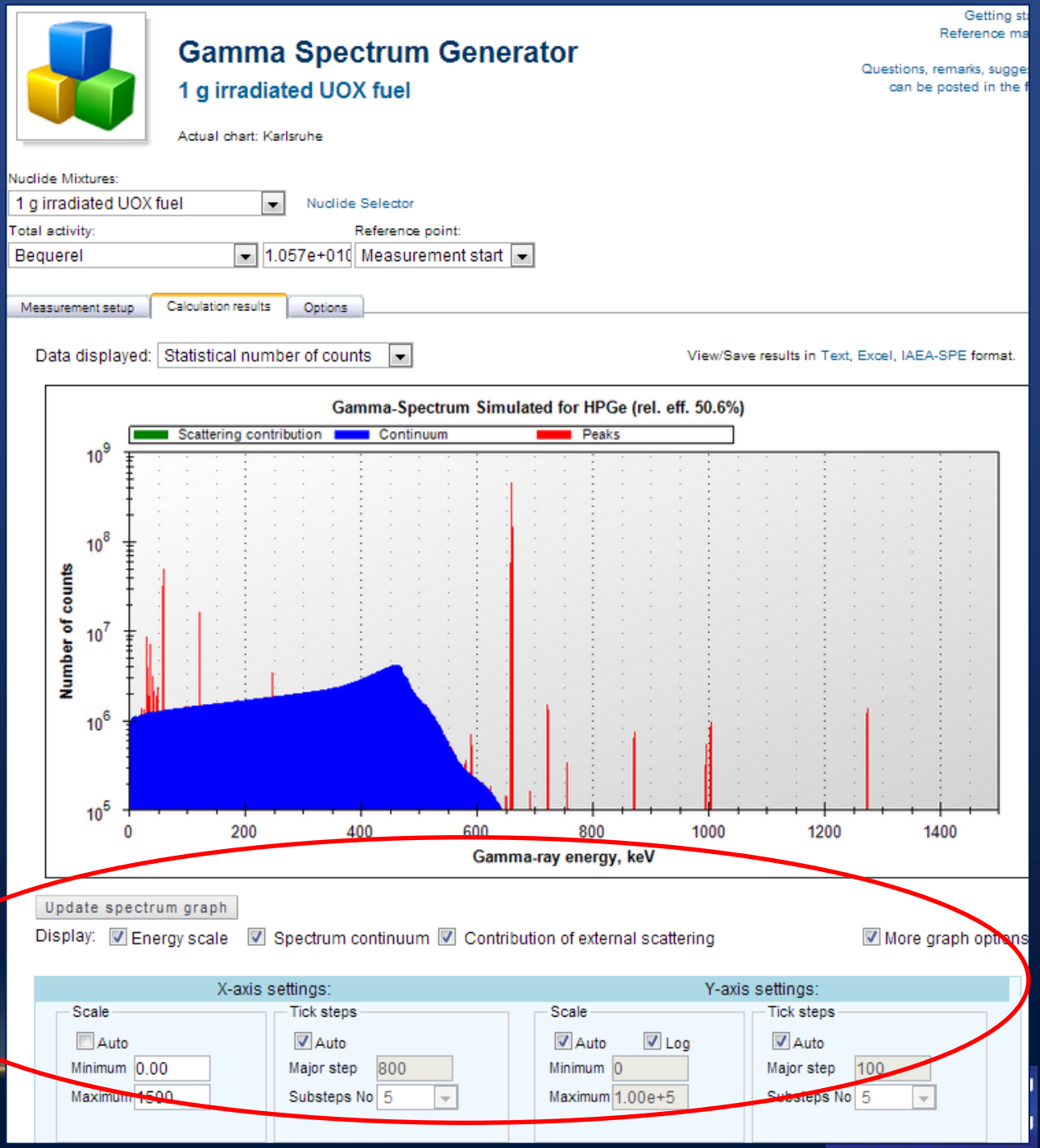
nucleonica

D: Generate the gamma spectrum for a HPGe detector (Gamma Spectrum Generator) and identify the main lines.

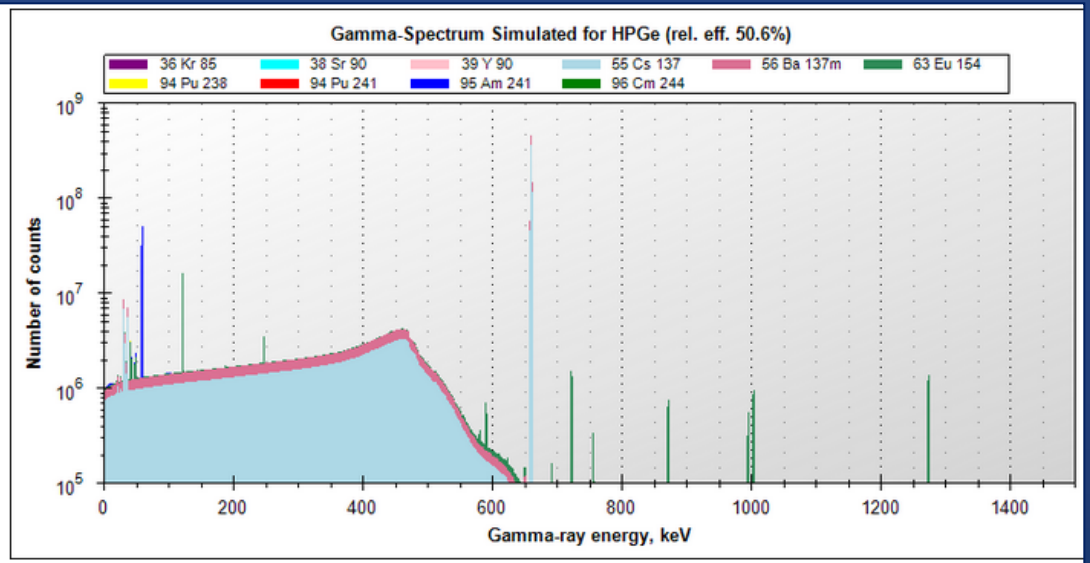


D: Generate the gamma spectrum for a HPGe detector (Gamma Spectrum Generator) and identify the main lines.

Results…



Identify the main lines in the spectrum (use filter shown below the spectrum)



Update spectrum graph

Display: Energy scale

More graph optic

X-axis settings:

Scale: Auto; Minimum 0.00; Maximum 1500

Tick steps: Auto; Major step 800; Substeps No 5

Grid lines: Major, Minor

Ticks: In, Out, Labels

Y-axis settings:

Scale: Auto, Log; Minimum 0; Maximum 1.00e+5

Tick steps: Auto; Major step 100; Substeps No 5

Grid lines: Major, Minor

Ticks: In, Out, Labels

No.	Nuclide	Count rate at start, cps	Count rate at end, cps	Spectrum counts	Display
1	"36 Kr 85"	6.31E+02	6.31E+02	6.30E+05	☑
2	"38 Sr 90"	0.00E+00	1.51E-04	0.00E+00	☑
3	"39 Y 90"	5.04E-02	5.03E-02	5.50E+01	☑
4	"55 Cs 137"	4.48E+01	5.98E+06	4.73E+09	☑
5	"56 Ba 137m"	6.05E+06	6.54E+04	1.32E+09	☑
6	"63 Eu 154"	1.84E+05	1.84E+05	1.84E+08	☑
7	"94 Pu 238"	1.22E+02	1.22E+02	1.22E+05	☑
8	"94 Pu 241"	4.59E+01	4.59E+01	4.56E+04	☑
9	"95 Am 241"	1.25E+05	1.25E+05	1.25E+08	☑
10	"96 Cm 244"	2.95E+01	2.95E+01	2.95E+04	☑
	Total	**6.36E+06**	**6.36E+06**	**6.36E+09**	

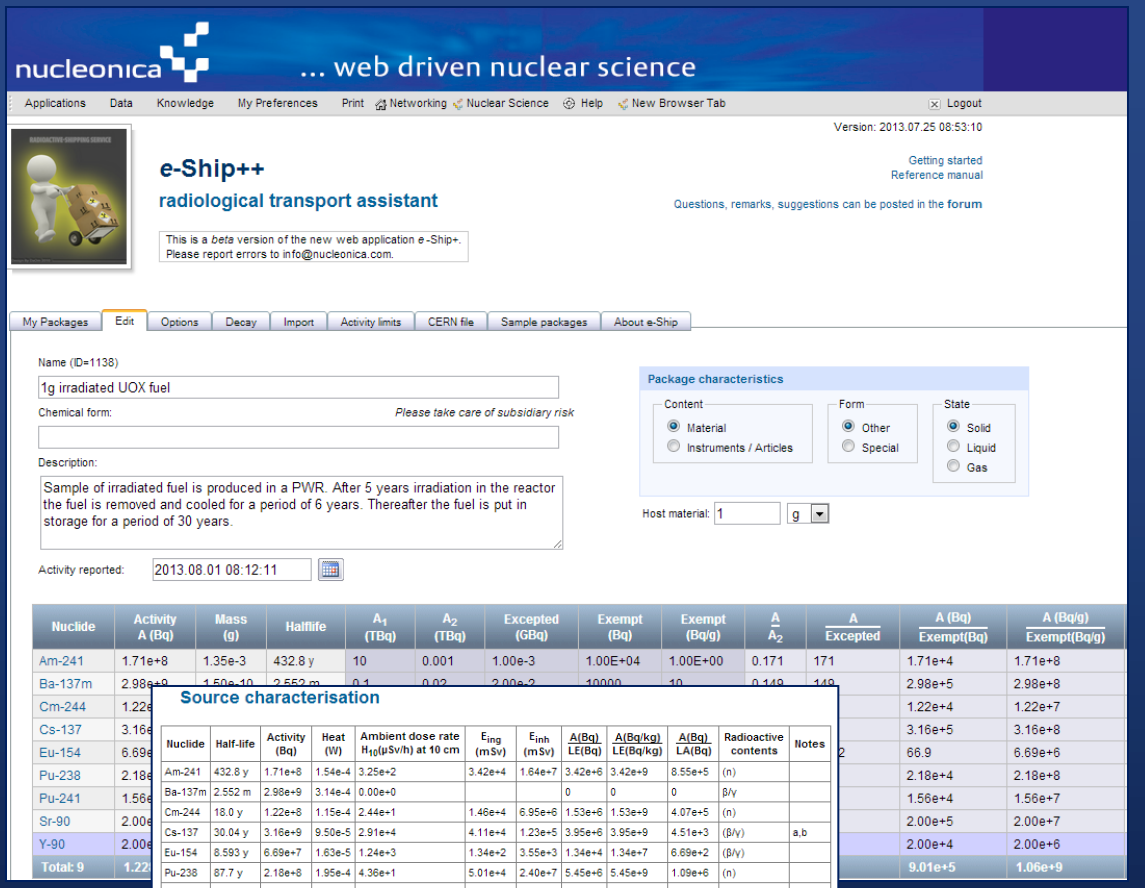
nucleonica

E: Generate a transport report to determine which type of packaging is required to transport this sample (e-Ship++)

1. Start the e-Ship application

2. Set the package characteristics (Material, Other form, Solid)

3. Generate the Transport report



Nuclide	Activity A (Bq)	Mass (g)	Halflife	A_1 (TBq)	A_2 (TBq)	Excepted (GBq)	Exempt (Bq)	Exempt (Bq/g)	$\frac{A}{A_2}$	$\frac{A}{\text{Excepted}}$	A (Bq) / Exempt(Bq)	A (Bq/g) / Exempt(Bq/g)
Am-241	1.71e+8	1.35e-3	432.8 y	10	0.001	1.00e-3	1.00E+04	1.00E+00	0.171	171	1.71e+4	1.71e+8
Ba-137m	2.98e+9	1.50e-10	2.552 m	0.1	0.02	2.00e-2	10000	10	0.149	149	2.98e+5	2.98e+8
Cm-244	1.22e										1.22e+4	1.22e+7
Cs-137	3.16e										3.16e+5	3.16e+8
Eu-154	6.69e									2	66.9	6.69e+6
Pu-238	2.18e										2.18e+4	2.18e+8
Pu-241	1.56e										1.56e+4	1.56e+7
Sr-90	2.00e										2.00e+5	2.00e+7
Y-90	2.00e										2.00e+4	2.00e+6
Total: 9	1.22										**9.01e+5**	**1.06e+9**

Source characterisation

Nuclide	Half-life	Activity (Bq)	Heat (W)	Ambient dose rate H_{10}(μSv/h) at 10 cm	E_{ing} (mSv)	E_{inh} (mSv)	$\frac{A(Bq)}{LE(Bq)}$	$\frac{A(Bq/kg)}{LE(Bq/kg)}$	$\frac{A(Bq)}{LA(Bq)}$	Radioactive contents	Notes
Am-241	432.8 y	1.71e+8	1.54e-4	3.25e+2	3.42e+4	1.64e+7	3.42e+6	3.42e+9	8.55e+5	(n)	
Ba-137m	2.552 m	2.98e+9	3.14e-4	0.00e+0			0	0	0	β/γ	
Cm-244	18.0 y	1.22e+8	1.15e-4	2.44e+1	1.46e+4	6.95e+6	1.53e+6	1.53e+9	4.07e+5	(n)	
Cs-137	30.04 y	3.16e+9	9.50e-5	2.91e+4	4.11e+4	1.23e+5	3.95e+6	3.95e+9	4.51e+3	(β/γ)	a,b
Eu-154	8.593 y	6.69e+7	1.63e-5	1.24e+3	1.34e+2	3.55e+3	1.34e+4	1.34e+7	6.69e+2	(β/γ)	
Pu-238	87.7 y	2.18e+8	1.95e-4	4.36e+1	5.01e+4	2.40e+7	5.45e+6	5.45e+9	1.09e+6	(n)	
Pu-241	14.33 y	1.56e+9	1.34e-6	<1.56e+2	7.49e+3	3.59e+6	7.80e+5	7.80e+8	1.73e+5	(n)	a
Sr-90	28.79 y	2.00e+9	5.57e-5	<2.00e+2	5.60e+4	3.20e+5	5.00e+6	5.00e+9	3.33e+4	(β/γ)	a,b
Y-90	2.671 d	2.00e+9	2.99e-4	1.40e+3	5.40e+3	3.00e+3	5.00e+5	5.00e+8	6.67e+2	(β/γ)	
Total: 9		**1.23e+10**	**3.52e-3**	**1.25e-3**	**<3.25e+4**	**2.09e+5**	**5.14e+7**	**2.06e+7**	**2.06e+10**	**2.56e+6**	

(a) A_1 and/or A_2 values include contributions from daughter nuclides with half-lives less than 10 days.
(b) Parent nuclides and their progeny included in secular equilibrium

e-Ship: nuclear material transport report

nucleonica

Transport report generated for source: 1g irradiated UOX fuel by magill on Aug 01, 2013 12:12:41

Package name: 1g irradiated UOX fuel
Description: Sample of irradiated fuel is produced in a PWR. After 5 years irradiation in the reactor the fuel is removed and cooled for a period of 6 years. Thereafter the fuel is put in storage for a period of 30 years.
Source: Material, Other form, Solid
Host material mass: 1 g
Activity reported: Aug 01, 2013 08:12:11
Subsidiary risk
Chemical form:
For the definition of the quantities used in this report see the Nucleonica Glossary

Source characterisation

Nuclide	Half-life	Activity (Bq)	Heat (W)	Ambient dose rate H_{10}(μSv/h) at 10 cm	E_{ing} (mSv)	E_{inh} (mSv)	$\frac{A(Bq)}{LE(Bq)}$	$\frac{A(Bq/kg)}{LE(Bq/kg)}$	$\frac{A(Bq)}{LA(Bq)}$	Radioactive contents	Notes
Am-241	432.8 y	1.71e+8	1.54e-4	3.25e+2	3.42e+4	1.64e+7	3.42e+6	3.42e+9	8.55e+5	(n)	
Ba-137m	2.552 m	2.98e+9	3.14e-4	0.00e+0			0	0	0	β/γ	
Cm-244	18.0 y	1.22e+8	1.15e-4	2.44e+1	1.46e+4	6.95e+6	1.53e+6	1.53e+9	4.07e+5	(n)	
Cs-137	30.04 y	3.16e+9	9.50e-5	2.91e+4	4.11e+4	1.23e+5	3.95e+6	3.95e+9	4.51e+3	(β/γ)	a,b
Eu-154	8.593 y	6.69e+7	1.63e-5	1.24e+3	1.34e+2	3.55e+3	1.34e+4	1.34e+7	6.69e+2	(β/γ)	
Pu-238	87.7 y	2.18e+8	1.95e-4	4.36e+1	5.01e+4	2.40e+7	5.45e+6	5.45e+9	1.09e+6	(n)	
Pu-241	14.33 y	1.56e+9	1.34e-6	<1.56e+2	7.49e+3	3.59e+6	7.80e+5	7.80e+8	1.73e+5	(n)	a
Sr-90	28.79 y	2.00e+9	5.57e-5	<2.00e+2	5.60e+4	3.20e+5	5.00e+6	5.00e+9	3.33e+4	(β/γ)	a,b
Y-90	2.671 d	2.00e+9	2.99e-4	1.40e+3	5.40e+3	3.00e+3	5.00e+5	5.00e+8	6.67e+2	(β/γ)	
Total: 9		**1.23e+10**	**3.52e-3**	**1.25e-3**	**<3.25e+4**	**2.09e+5**	**5.14e+7**	**2.06e+7**	**2.06e+10**	**2.56e+6**	

(a) A_1 and/or A_2 values include contributions from daughter nuclides with half-lives less than 10 days.
(b) Parent nuclides and their progeny included in secular equilibrium

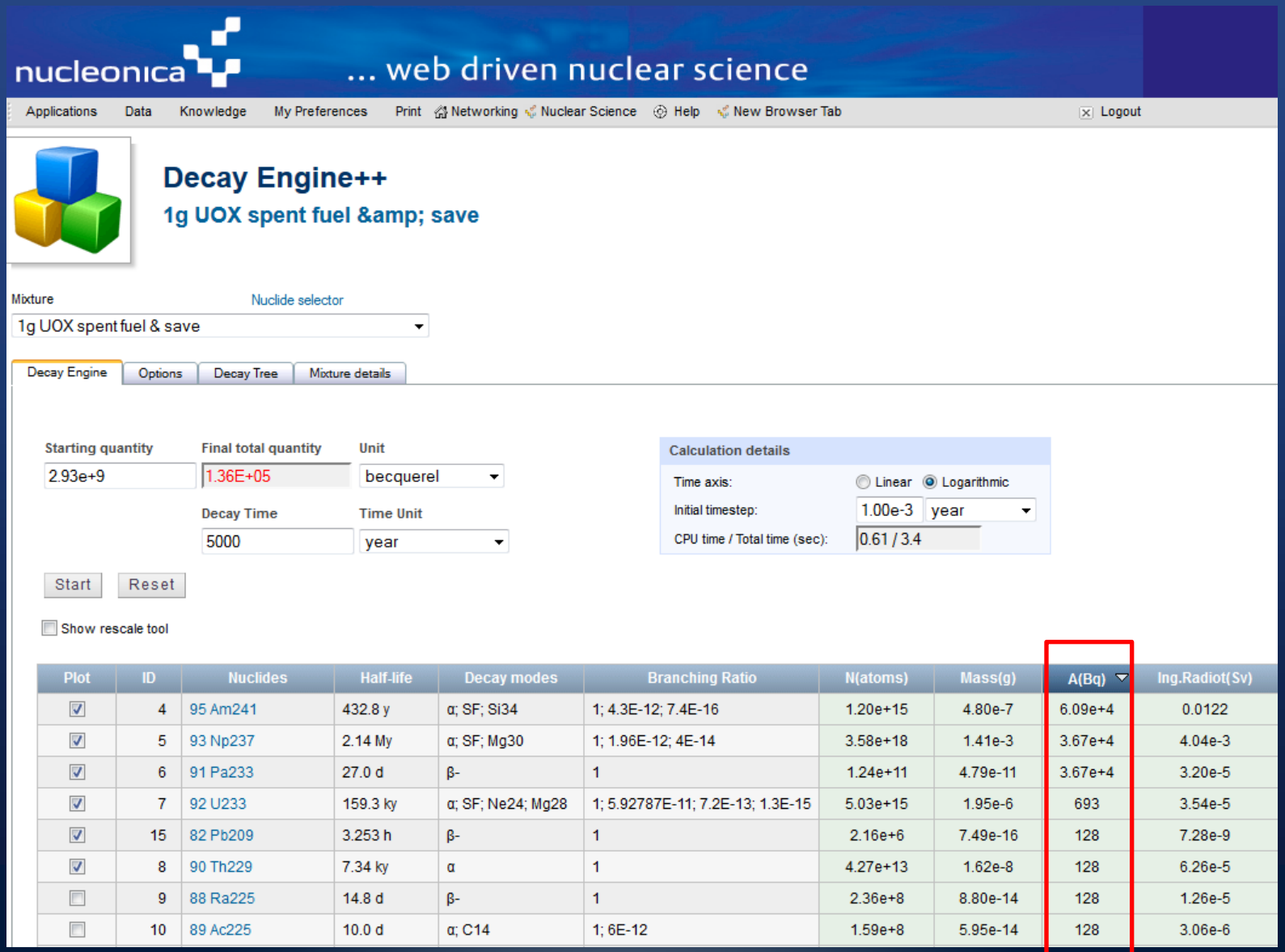
Package characterisation

Nuclide	Activity (Bq)	A_2 (TBq)	Exempt (Bq)	Exempt (Bq/g)	Excepted (GBq)	$\frac{A}{A_2}$	$\frac{A}{\text{Exempt}}$	$\frac{A(Bq/g)}{\text{Exempt}(Bq/g)}$	$\frac{A}{\text{Excepted}}$
Am-241	1.71e+8	1.00e-3	1.00e+4	1.00e+0	1.00e-3	1.71e-1	1.71e+4	1.71e+8	1.71e+2
Ba-137m	2.98e+9	2.00e-2	1.00e+4	1.00e+1	2.00e-2	1.49e-1	2.98e+5	2.98e+8	1.49e+2
Cm-244	1.22e+8	2.00e-3	1.00e+4	1.00e+1	2.00e-3	6.10e-2	1.22e+4	1.22e+7	6.10e+1
Cs-137	3.16e+9	6.00e-1	1.00e+4	1.00e+1	6.00e-1	5.27e-3	3.16e+5	3.16e+8	5.27e+0
Eu-154	6.69e+7	6.00e-1	1.00e+6	1.00e+1	6.00e-1	1.12e-4	6.69e+1	6.69e+6	1.12e-1
Pu-238	2.18e+8	1.00e-3	1.00e+4	1.00e+0	1.00e-3	2.18e-1	2.18e+4	2.18e+8	2.18e+2
Pu-241	1.56e+9	6.00e-2	1.00e+5	1.00e+2	6.00e-2	2.60e-2	1.56e+4	1.56e+7	2.60e+1
Sr-90	2.00e+9	3.00e-1	1.00e+4	1.00e+2	3.00e-1	6.67e-3	2.00e+5	2.00e+7	6.67e+0
Y-90	2.00e+9	3.00e-1	1.00e+5	1.00e+3	3.00e-1	6.67e-3	2.00e+4	2.00e+6	6.67e+0
Total: 9	**1.23e+10**					**6.44e-1**	**9.01e+5**	**1.06e+9**	**6.44e+2**

Type A Package

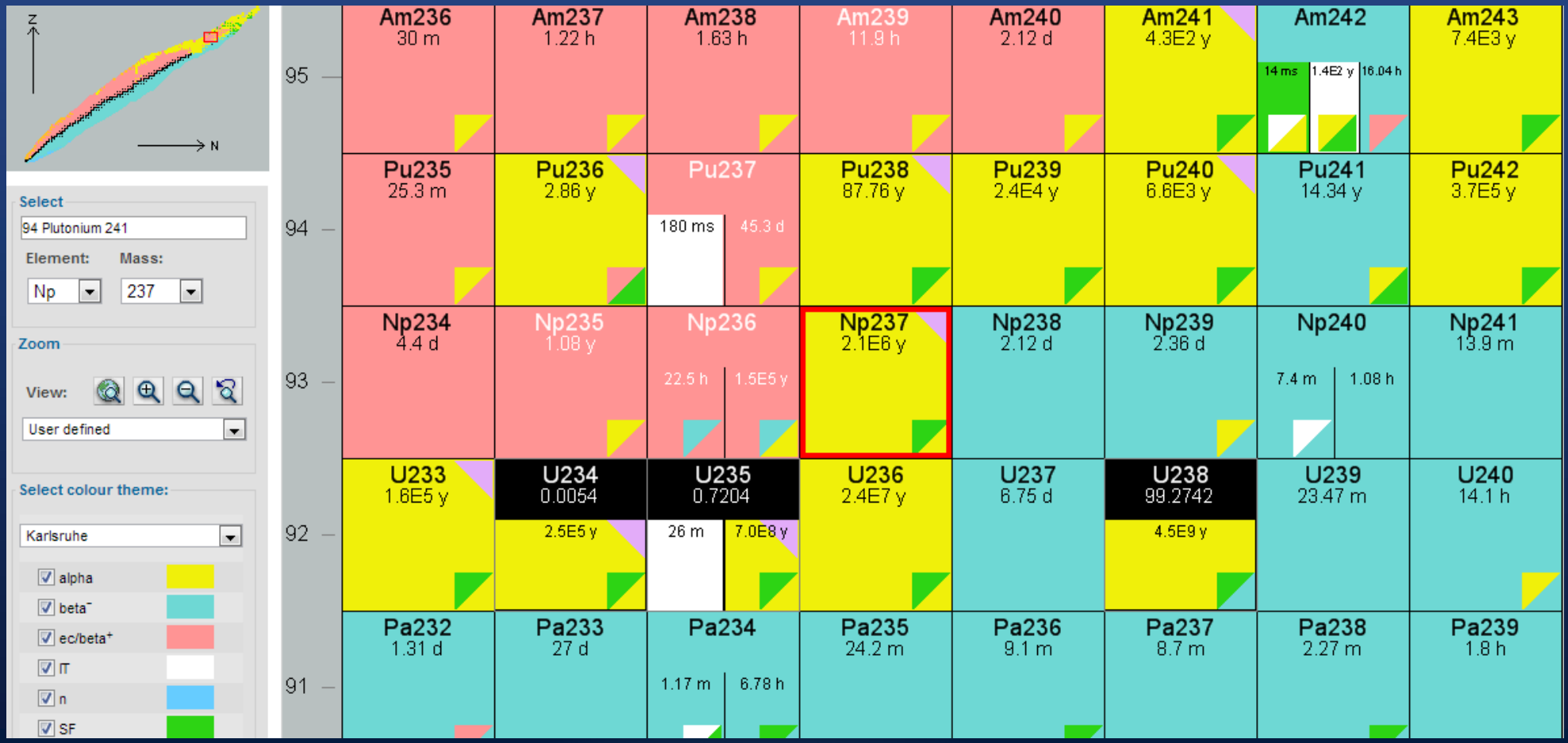
nucleonica

F: Use the Decay Engine++ to see how the activity of the sample decreases over 5000 y.



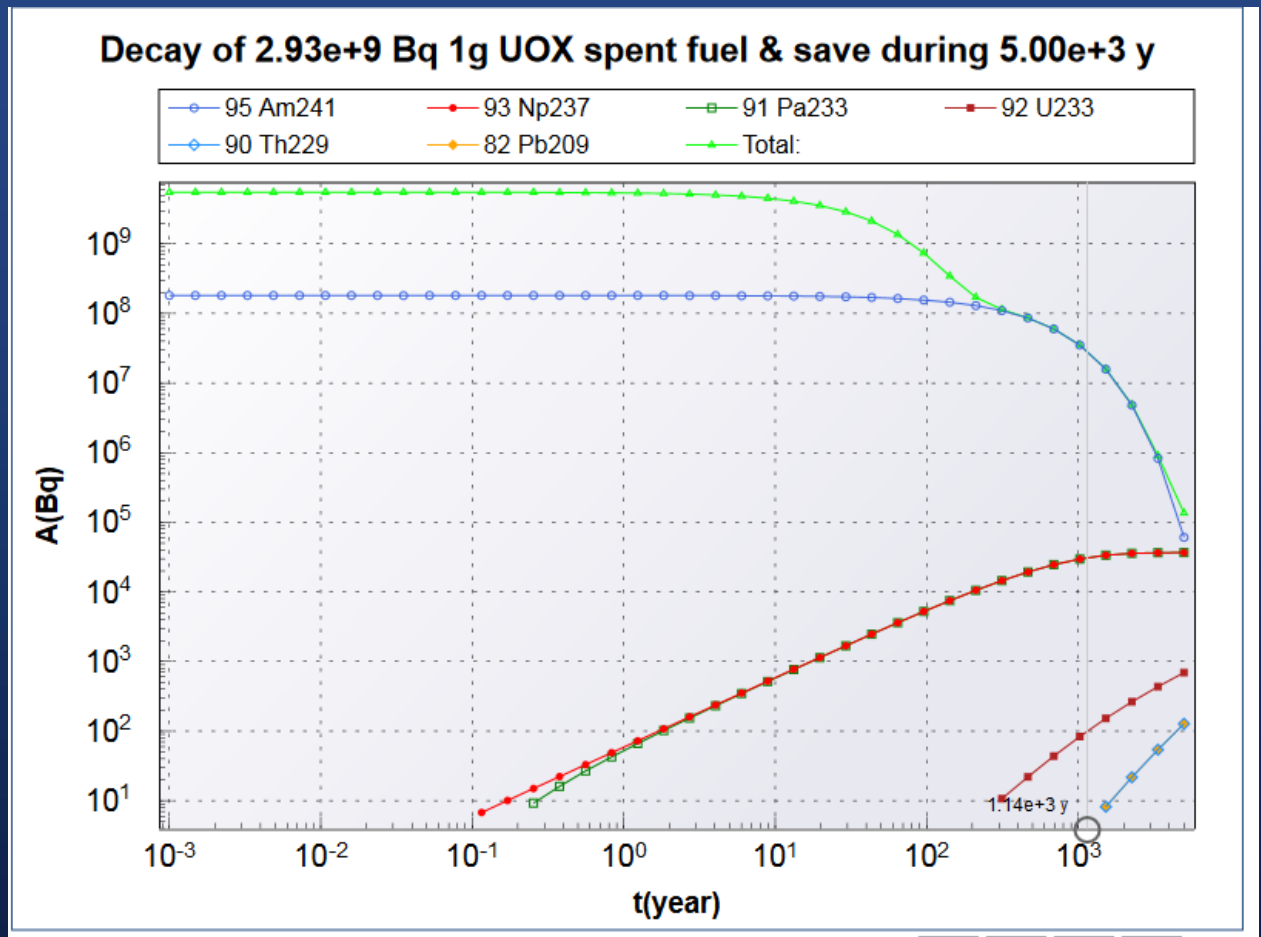
Plot	ID	Nuclides	Half-life	Decay modes	Branching Ratio	N(atoms)	Mass(g)	A(Bq)	Ing.Radiot(Sv)
☑	4	95 Am241	432.8 y	α; SF; Si34	1; 4.3E-12; 7.4E-16	1.20e+15	4.80e-7	6.09e+4	0.0122
☑	5	93 Np237	2.14 My	α; SF; Mg30	1; 1.96E-12; 4E-14	3.58e+18	1.41e-3	3.67e+4	4.04e-3
☑	6	91 Pa233	27.0 d	β-	1	1.24e+11	4.79e-11	3.67e+4	3.20e-5
☑	7	92 U233	159.3 ky	α; SF; Ne24; Mg28	1; 5.92787E-11; 7.2E-13; 1.3E-15	5.03e+15	1.95e-6	693	3.54e-5
☑	15	82 Pb209	3.253 h	β-	1	2.16e+6	7.49e-16	128	7.28e-9
☑	8	90 Th229	7.34 ky	α	1	4.27e+13	1.62e-8	128	6.26e-5
☐	9	88 Ra225	14.8 d	β-	1	2.36e+8	8.80e-14	128	1.26e-5
☐	10	89 Ac225	10.0 d	α; C14	1; 6E-12	1.59e+8	5.95e-14	128	3.06e-6

F: Use the Decay Engine++ to see how the activity of the sample decreases over 5000 y.



nucleonica

F: Use the Decay Engine++ to see how the activity of the sample decreases over 5000 y.

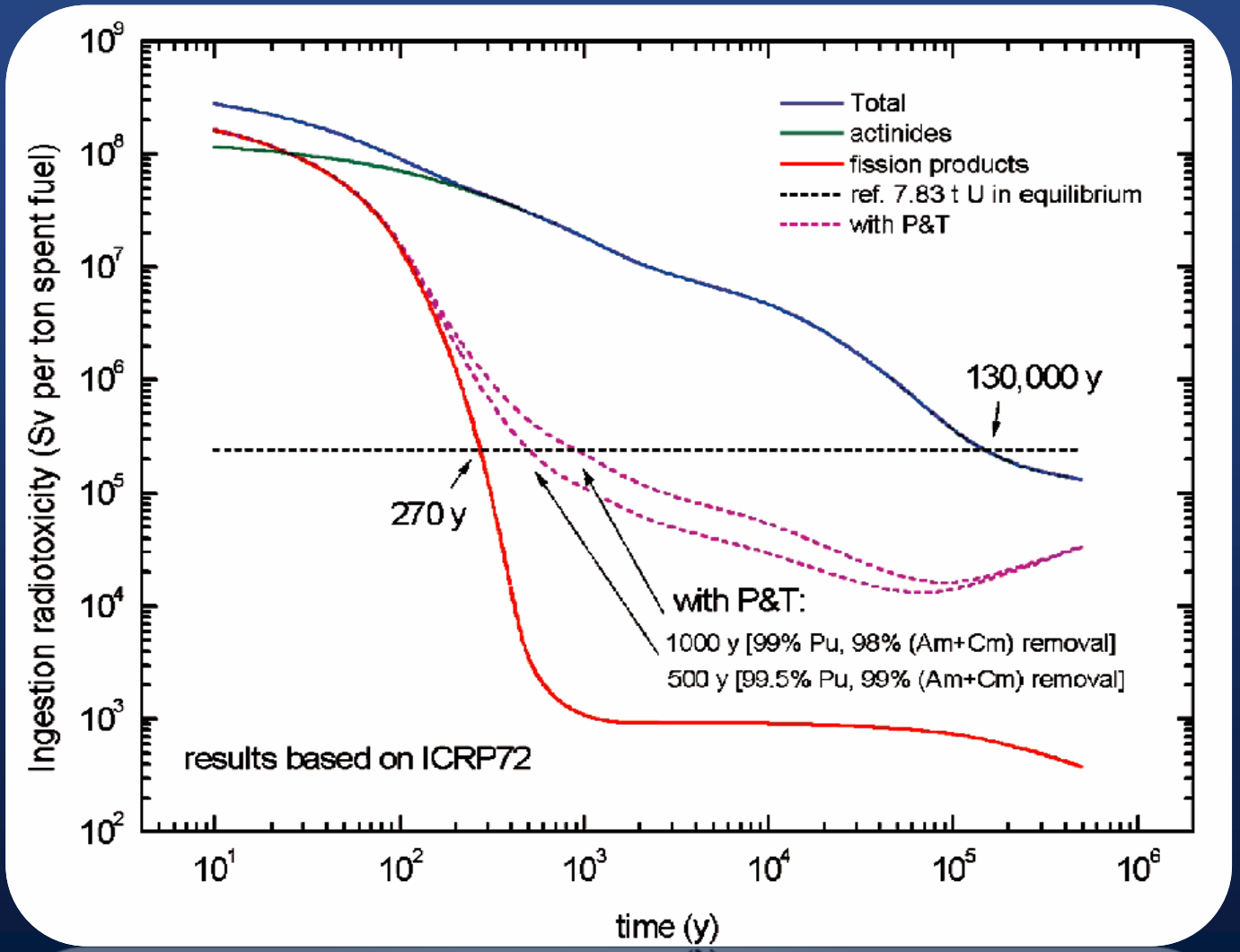


Cursor at: 1.14e+3 year

Curve	Nuclide	Activity (Bq)
	95 Am241	2.87e+7
	93 Np237	3.06e+4
	91 Pa233	3.06e+4
	92 U233	97.4
	90 Th229	3.83
	82 Pb209	3.83
	Total:	2.88e+7

Activity decreases by factor 100 in 1140 y

nucleonica


Ingestion radiotoxicity (Sv per ton spent fuel)
time (y)
Total
actinides
fission products
ref. 7.83 t U in equilibrium
with P&T
130,000 y
270 y
with P&T:
1000 y [99% Pu, 98% (Am+Cm) removal]
500 y [99.5% Pu, 99% (Am+Cm) removal]
results based on ICRP72

nucleonica

Case Study: Characterisation of an Irradiated fuel sample (UOX) from a PWR

A: Calculate the activities of actinide and fission products in the sample (webKORIGEN)

B: Create a nuclide mixture of the 10 nuclides with highest activities (Nuclide Mixtures)

C: Estimate the gamma dose rate from this material – both unshielded and shielded (Dosimetry & Shielding)

D: Generate the gamma spectrum for a HPGe detector (Gamma Spectrum Generator) and identify the main lines.

E: Generate a transport report to determine which type of packaging is required to transport this sample (e-Ship)

F: Use the Decay Engine++ to see how the activity of the sample decreases over 5000 y.